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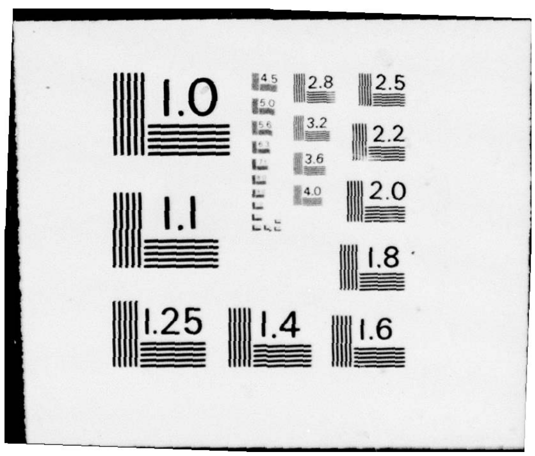
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PRESENT STATE OF THE ART AND TRENDS IN THE DEVELOPMENT OF HYDROFOILS

[Milovanov, E. V.; Sovremennoye sostoyaniye i tendentsii razvitiya sudov na podvodnykh kryl'yakh; Sudostroyeniye, No. 9, 1972, pp. 10-17; Russian]

Twenty years ago the first hydrofoil in the world entered the waterways. At the present time /1972/ more than a thousand hydrofoils are estimated to be in the world. Of these more than 80% were built in the Soviet Union /1-3/.

For the longest time marine transport remained the slowest with respect to speed of motion. The rapid increases in air and ground speeds threatened to deprive ships of their role in the overall system of transport means. The average speeds on water remained 15-20 knots, while ground transport reached speeds of 200 km/h and air transport broke the sound barrier. Even the significant increase in the power of the propulsion plants of hull-borne ships has imparted a slightly perceptible speed increment over 20-30 knots. As is known, this is caused by the cubic relationship between underway speed and tow power and, consequently, the power on the engine shaft expressed by the formula $N_e = \frac{D^{2/3}V^3}{C}$.

It is apparent that the solution of the problem of marine transport speed has to be sought in essentially new ideas. Thus, the idea of lifting the hull out of the water was advanced. In doing this, the main component of total drag, the wave resistance, disappears. Hydrofoils or air cushion vehicles could be the means to do this.

The first patent for a craft with hydrofoils was issued in France in 1891 to a Russian subject Lambert. The results of successive investigations in various countries made it possible for the Canadian engineers Bell, Baldwin, and Rhodes to develop the HD-4 hydrofoil (displacement 5 t) in 1918-19. For a long time this launch held the world speed record on water, 61.5 knots. The next stage in the development of hydrofoils was the working out of the theoretical principles of design. A large contribution to the theory of hydrofoils in the 1930's was made by the Soviet researchers M. V. Keldysh, M. A. Lavrent'yev, N. Ye. Kochin, A. I. Vladimirov, and others. Important work was done by the German investigators H. Schertel, O. Tietjens, and Sachsenberg. The last two decades have been concerned with

the practical use of hydrofoils on inland waterways and sea routes.

The hydrofoil effect is caused by the property of liquid flow continuity. The upper and lower planes of the foil are given a different curvature so that the upper line of the profile is longer than the lower. When there is motion, the liquid flows over the upper plane with a greater velocity than the lower, and a rarified zone forms above. As a result of the pressure drop, lift is created. The development of the theoretical principles of hydrofoils led to their serial production. In the Soviet Union ships of this new type entered the regular lines in 1957. The Soviet ships RAKETA, METEOR, BELARUS', KOMETA, STRELA, VIKhR, the launch VOLGA, and others that are known not just in the Soviet Union but far beyond her borders. A considerable contribution to the development of the new type of ship was made by a team of Gor'kiy designers headed by Doctor of Technical Sciences R. Ye. Alekseyev. The popularity of the Soviet hydrofoils is attested by the fact that at the Third International Conference on the Prospects of Hydrofoils and Air Cushion Vehicles (London, 21-22 October 1970) several reports were given on ships of Soviet construction /3, 4/.

The first generation of hydrofoils, built in the 1950's and 1960's, was designed to operate on rivers and lakes. Minor improvements permitted them to be used on coastal lanes. Among such ships were the hydrofoils KOMETA, STRELA, VIKhR', PT 20/59, PT 50, and others. Their seaworthiness was limited to sea states of 304 (and in some instances 5). Quite indicative of the seaworthiness of hydrofoils was the journey of one of the modernized KOMETA-M craft around Europe. The 11,500-mile cruise (with calls at 34 ports in 15 countries) continued from May through September 1971. En route the ship encountered a 5-point storm. According to the crew, KOMETA-M behaved beautifully in the rough weather. Non-Soviet specialists noted the successful long cruise of the Soviet hydrofoil, which was especially crowned by orders for the hydrofoils /5/.

The further development of hydrofoils was connected with their entry into the open sea. This increased the requirements put on hydrofoil seaworthiness, power, and strength characteristics. The leading role in the development of these ships is occupied by the USSR and Switzerland. Italy and Japan, as before, build hydrofoils on license from the Swiss Supramar company. At the same time they are attempting to develop their own seagoing hydrofoils (Fig. 1). The United States and Canada in their work pursue mostly military aims.

Realizing the potential of the new kind of marine transport is associated with the solution of several problems. The main ones are the development of seaworthy hydrofoil systems and small, high-power propulsion plants. The seaworthy foil system should possess a regular lift value. The last named depends on the seawater density, the speed of the oncoming flow, and the foil area. It is expressed by the formula

$$Y = C_y \rho \frac{V_0^2}{2} F,$$

where C_y is the lift coefficient.

When foilborne the lift equals the weight of the ship, i.e., Y = D. At the same time, drag that is dependent on the same factors as is the lift is acting on the foil. The difference consists only in the drag coefficient value. Affecting the lift coefficient values and drag values are the foil profile form, angle of attack, aspect ratio, and its relative submergence. The lift to drag ratio is called the foil's hydrodynamic factor. The higher the value, the more advanced the foil.

In the first stage the various foil profiles were worked out. Later, two profiles -- plane convex and asymmetrical double convex -- were used in practice. The plane convex profile is widely used for slightly submerged and semisubmerged foils. The first were developed in the Soviet Union.

Self-stabilization of slightly submerged foils occurs due to the effect of the proximity of the free surface. In the operating mode the thickness of the layer of water above the upper (intake) plane should be about equal to the foil chord. When the thickness is less, air from the atmosphere is sucked into the foil causing a pressure drop and a sharp drop in lift. The reverse picture is observed if the foil is submerged when waves are coming in. It is not expedient to use slightly submerged foils on seagoing ships because of their "sensitivity" to wave action. But in coastal sea lanes such foils, after some modification, can manage in sea states of 3-4 /1/.

Semisubmerged foils intersecting the water surface are widely used on non-Soviet hydrofoils. The end pieces of such foils protrude above the water. Lifting or submerging them during ship movement decreases or increases the wet surface area. Depending on this, lift, i.e., self-stabilization of the ship, rises or falls. Semisubmerged foils are characteristic of Supramar company projects. In the Soviet Union analgous foils have been used on the NEVKA seagoing excursion launch (Fig. 2), and on the STRELA. To increase the stabilizing factors, the foil is given various keel shapes (angle of flare) in the deeply submerged parts and parts intersecting the water surface /6, 7/. For example, this kind of foil is used as the forward foil on the PT-50, built by the Supramar company.

A foil that intersects the water surface consists of slightly submerged and deeply submerged sections. To increase the area of the deeply submerged sections that are not subject to the effects of wave action, horizontal elements of the foil are used. Such foils are used on the PT 20, the Italian H 57 (Fig. 3), and some others. The effect of wave action ship performance in the open sea can be eliminated by means of deeply and completely submerged foils. This means that the foil sub-

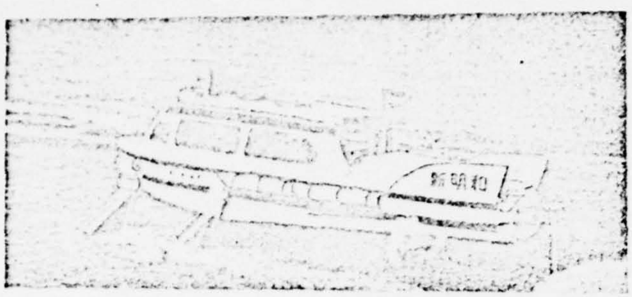

Fig. 1. Japanese 14-man SF-30 Hydrofoil Launch

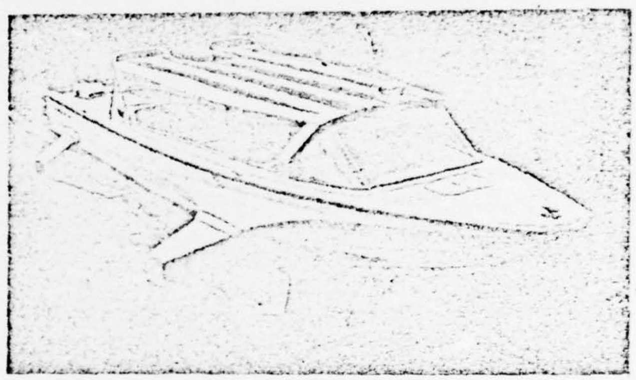

Fig. 2. Soviet Seagoing Passenger Hydrofoil Launch NEVKA

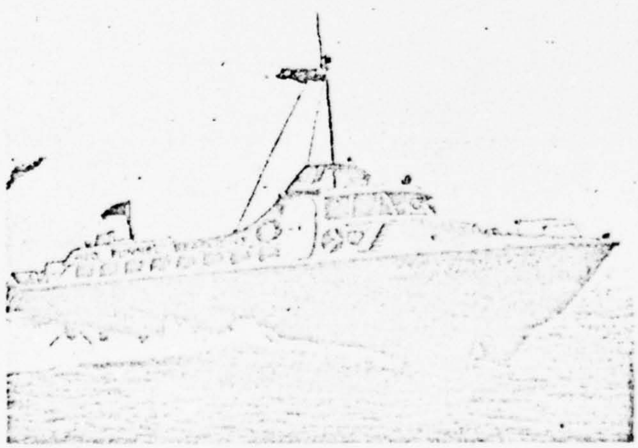

Fig. 3. Italian Passenger Ship SEAFLIGHT H.57

mergence depth in all modes of operation should exceed the value of the profile chord. The profile of deeply submerged foils is, as a rule, double convex. In this case a constant lift value is provided by the forced change of the angle of attack. For the seagoing hydrofoils of the second generation in recent years, an automatic control system for the foil angle of attack has been successfully introduced. Special sensors monitor the foil position relative to the water surface, sending signals to the control mechanisms. The latter regulate the foil angle of attack or the flap position. The flaps are especially used on the TAYFUN (Fig. 4). Automatic flap control ensures smooth hydrofoil motion and a constant 1.5-m clearance. The ship's operational speed is 42 knots on still waters and 38 knots in sea states of 4. Ship remains seaworthy to a sea state maximum of 5 /8, 9/.

Besides the Soviet Union, the United States is very active in developing completely submerged automatically controlled foils. The DOLPHIN /10/ has such foils and its military version FLAGSTAFF (Fig. 5) also, so do the HIGH POINT and TUCUMCARI. The last named is a gun ship and has been in service since 1967. Experience in its operation has apparently been successful since American specialists use it as prototype for new projects. On the basis of the TUCUMCARI the Boeing Company has developed a promising program of developing 540-t and 4400-t displacement hydrofoils /11/. TUCUMCARI has also served as prototype for the Italian cutter ALINAVI (50-t displacement) and an American ferry project for 300 passengers. For demonstration purposes the TUCUMCARI in 1971 visited various West European countries /12/.

Automatic control foil systems are still very expensive, complicated to operate, and insufficiently reliable. On the basis of the hydrodynamic factor they are inferior to fixed foil systems by a factor of 1½-2 /1/. Nonetheless, automatic control is considered most promising for seagoing hydrofoils. Experience shows that by means of it waves 4 m high and greater can be managed.

Presently, a foil system in which air is artificially sent to the foils is being developed (it is known as the Schertel-Supramar system). Essentially it is based on changing the lift coefficient C_y by sending air to the foil plane. Having provided and regulated the design air flow value, the value of C_y can be controlled so that the ship can operate stably on rough waters. Artificial ventilation of the foil also results in some increase in the hydrofoil's hydrodynamic factor at precavitational speeds (up to 50 knots). During the ventilation process the air is mixed with the water flow which has not yet separated from the foil. Turbulence in the boundary layer is increased, the layer itself becomes thicker and diverges. Owing to the air layer behind the foil, it is as if the profile length had increased. This leads to an increased water circulation around the profile, a pressure redistribution, and a change in lift. At speeds greater than cavitational speeds the hydrodynamic factor can be increased through the form and size of the cavitational cavities /1/.

A theory explaining the foil ventilation effect is now being developed /13/. The ventilation method was practically realized on one of the PC 50's produced by the Supramar company (Fig. 6). Trials proved the improvement in the ship's seakeeping abilities: heeling reduced (to 48%), trim reduced (to 66%), vertical accelerations reduced (to 40%), speed in rough waters increases, and turning circle diameter decreased /14/. However in still waters the speed decreased, the hydrofoil showed the low sluggishness of the new system /15/. Foils with artificial ventilation have been installed on the large PTS 150 Mk III QUEEN OF WAVES and PRINCESS OF WAVES hydrofoils (Fig. 7).

A new method of roll stabilization also found application on the experimental Canadian hydrofoil BRASD'OR (Fig. 8). Its rotating forward auxiliary foil is provided with a ventilation system. The ship's foil system is known as the "canard." Unlike conventional systems, the after foil, mounted on ¼ the hull length from the stern, is the bearing surface. From the point of view of American and Canadian specialists, this arrangement provides a high degree of longitudinal stability when traveling rough waters. This is effected by the soft characteristic of the forward auxiliary foil with slow change in lift value as depth of submergence changes. On the other hand, the after foil which intersects the water surface has a rigid characteristic of lift increase as submergence depth increases. The practical constancy of this characteristic makes it easy to regulate the forward foil lift by sending air. The slight lift increment causes (in the case of trim) the occurrence of a righting moment relative to the center of gravity which shifted towards the after foil. This moment is sufficient to bring the angle of attack of the bearing foil, and with it the lift, to the calculated value.

The system of artificial foil ventilation described above is considered more acceptable for seagoing hydrofoils than the automatic control system. Its advantages consist in the lesser complexity and great simplicity of servicing, low cost, and high reliability. Still another foil system was proposed for the second generation hydrofoils. This system, known by the name Hamilton Standard is a dual axle, rotating, W-shaped foil that intersects the water surface. Such foils are used on the new series of RHS hydrofoils put out by the Italian Rodriquez company (Fig. 9). The foil is attached to bearing of a shaft passing across the ship's hull. This makes it possible to change angle of attack α. The foil does not deviate under the pressure of the water because of a special mechanism that reacts to impact loads, thereby enhancing the foil serviceability.

With the appearance of hydrofoils speeds on water increased to 30-35 knots. It is expected in the future that they will increase by no less than two times. Even now hydrofoils having speeds up to 70 knots are being developed. But to reach these speeds the cavitational barrier will have to be broken. Cavitation occurs at that moment when the pressure

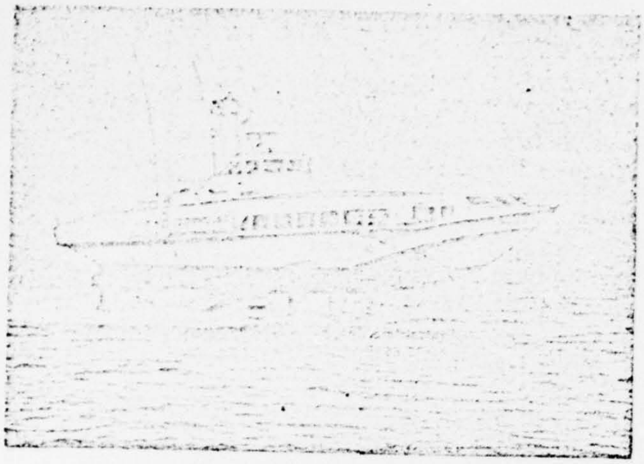

Fig. 4. Soviet Ship on Automatically Controlled Foils TAYFUN

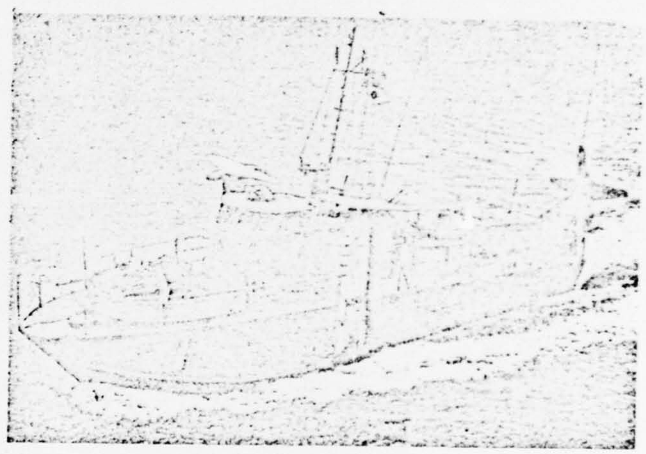

Fig. 5. U. S. Hydrofoil FLAGSTAFF Hullborne (Foils Lifted)

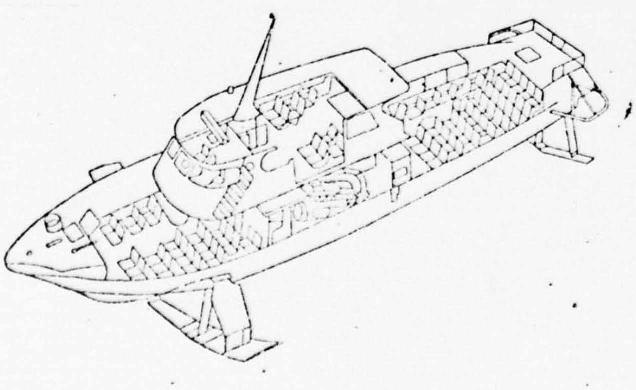

Fig. 6. Hydrofoil PT 50 Built by Supramar Company

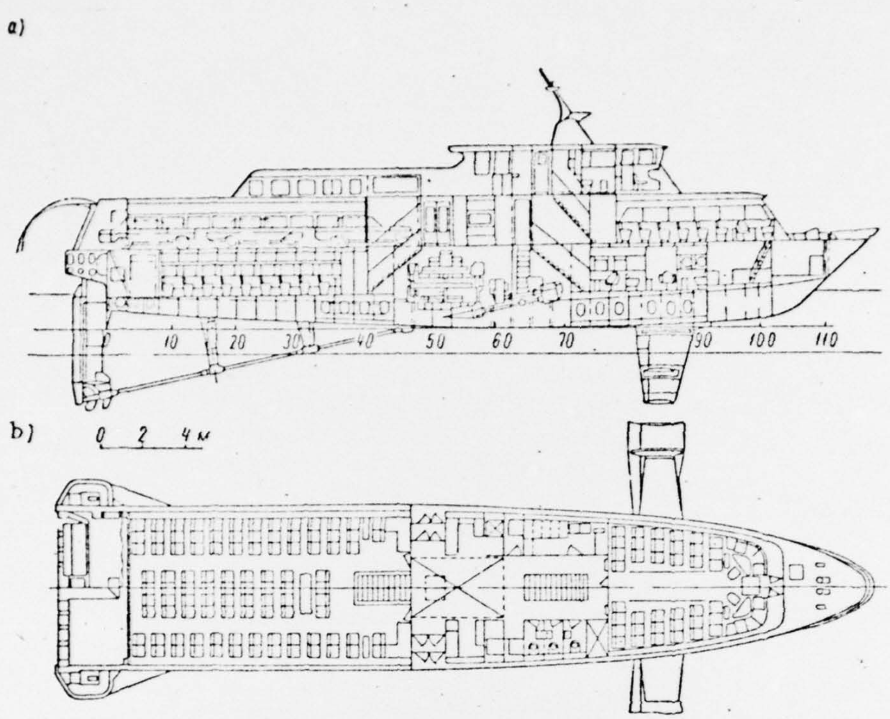

Fig. 7. Norwegian Built (Supramar Design) Passenger-Automobile Hydrofoil Ferry QUEEN OF WAVES
a - longitudinal section; b - topview of main deck

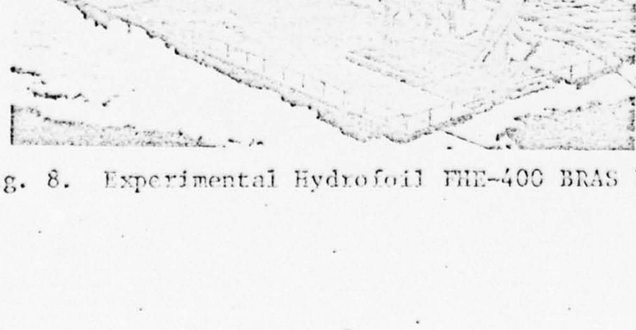

Fig. 8. Experimental Hydrofoil FHE-400 BRAS D'OR

on the intake surface becomes less than the pressure of the saturated water vapors. Vapor condensation causes erosion of the foil surface at the contact point with the cavitation cavity. Surface erosion and reduction of the hydrodynamic factor of the foil results in a decrease in lift. There are two ways of solving the cavitation problem. First, it is possible to postpone the moment of onset of cavitation to the high speeds beyond the limits of the designed mode. Second, it is possible to stretch out the cavitational cavity through the entire length of the profile so that its contact occurs aft of the foil. The second way is considered more promising. The use of the so-called "supercavitating" mode permits high speeds to be developed without reduction of the foil's hydrodynamic factor. As early as the 1930's it was understood that the forward sharp edge of the profile facilitates the rapid separation of the boundary layer from the surface. The cavitational cavity formed in this process develops with increased speed. Spreading the air cavity through the entire length of the profile in an early stage of motion permits practically unlimited speeds to be developed.

The supercavitating mode is achieved by the selection of a profile whose streamline flow is affected by the shape of the forward edge and pressure (lower) surface. The load on this foil should be perceived by the stronger after part. With this in mind, supercavitating profiles with an increasing theoretical hydrodynamic factor maximum have been developed /16/. They have a thin forward edge and pressure surface of rounded curvature, as well as curvatures of the second, third, and fifth orders (Fig. 10). The former are effective in the case of low lift values. A profile with curvature of the second order has found practical application in seagoing hydrofoils currently being designed and built (especially in the BRAS D'OR). Profiles with pressure surface curvature of the third and fifth orders are theoretically more effective. The lift in them occurs in the after edge, and the hydrodynamic factor can reach high values (of the order of 100). However, in practice, hydrodynamic factor values of not more than 8-10 have so far been achieved.

At the present time supercavitating foils are used at speeds of 50 knots and above. Reference /17/ investigates V-shaped foils for these modes with so-called partial stall profile. Combining the supercavitating foil with artificial ventilation improves operating conditions. Air sent to the cavity accelerates the onset of cavitation, thereby facilitating the rapid development of adequate lift and foilborne operation.

It had previously been thought that an increase in hydrofoil displacement leads to a significant growth of the relative weight of the foil system. At the present time, this value is ~20% of the displacement. Investigations have shown that in the future the relative weight can be maintained and even reduced. Most optimistic are the expressed possibilities of reducing the relative weight of completely submerged

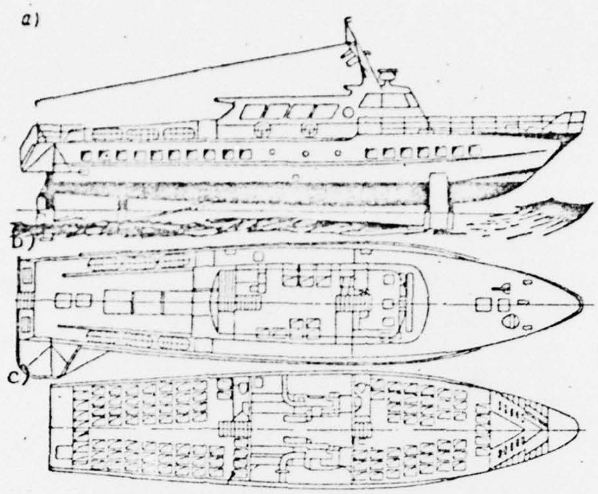

Fig. 9. Italian 125-Passenger Hydrofoil Ferry RHS 140: a - side view; b - topview of main deck; c - topview of salon and engineroom

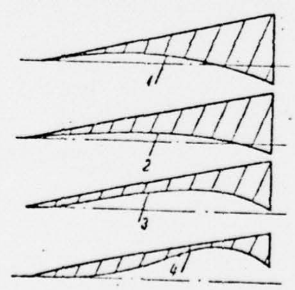

Fig. 10. Profiles of Supercavitating Hydrofoils. 1 - with rounded curvature of pressure surface; 2, 3, 4 - with curvature of second, third and fifth orders

completely submerged automatically controlled foils to 10% /18/. In this, significant technological difficulties associated with increasing the size and strength of the foil systems capable of supporting the considerable dynamic loads unavoidably arise. The building of struts to secure deeply submerged foils to the hull becomes more complicated, and the arrangement of the shafts in them to transmit power from the main engines to the propellers becomes more difficult.

Small high-speed diesels with inclined shafts for power transmission were widely used as main engines on first generation hydrofoils (Table 1).

Table 1

Characteristics of Main Engines of First Generation Hydrofoils /19/

Diesel power hp	Specific mass kg/hp	Specific fuel rate, kg/hph	Period between servicing, h
Up to 1000	4.5-11.3	0.18	2500
1000-3000	4.5-6.8	0.17	3000-5000

The extreme angle of inclination of the propeller shaft at which normal engine and propeller operation is possible is 12°. When the clearance is increased (clearance between hull bottom and water surface when foilborne), the propeller shaft angle of inclination increases. As a result the engine operational conditions become poorer as does the nature of the flow around the propellers and, consequently, the propulsion coefficient decreases sharply. The use of gas turbines and angular drives is a departure. Gas turbines with angular drive columns were installed on the American hydrofoils DOLPHIN, DENISON, and VICTORIA, as well as on the Soviet hydrofoils BUREVESTNIK and TAYFUN. The TAYFUN, designed for 100 passengers, was equipped with two 1700-hp AI-23s gas turbines operating on diesel fuel. The power is transmitted to two propellers through K-1700 angular drive columns. In the hullborne position a 160-hp slow-speed diesel engine operates the propellers mounted on double rotating KP-150 lift column /8/.

Angular mechanical transmissions using vertical columns have high efficiency, light weight, and small size. Therefore they have found ever greater use in seagoing hydrofoils, despite their high cost and complexity. There are drive columns designed to transmit powers up to 20,000 hp (DENISON). They provide considerable clearance during hydrofoil operation and a high propulsion coefficient of the propulsion system. Specifically, the hydrofoil PLAINVIEW has a foil strut height of 7.6, and drive columns of 9 m, making possible foilborne operation in waves up to 4.6 m high.

In the future, as size, displacement, load-carrying capacity, speed,

and seaworthiness of hydrofoils increase, a wider use of gas turbines must be expected. Diesels will remain only on relatively small and slow ships. This is illustrated by the data in Table 2. The fact is that piston engines having a power over 6000 hp have large weight-size characteristics. Presently, gas turbine units are under development that develop great power although they are relatively small and light. The American Pratt and Whitney Company build FT type marine gas turbines having powers of 24,200, 26,950, and 31,200 ehp at 3600 rpm and exhaust gas temperatures of 338-476°C /20/. The use of such engines on nonmilitary ships is still hindered by their high cost and high fuel consumption. The prospects of gas turbine units are also influenced by the current tendency toward reducing the specific cost of the power units as power increases. Moreover, in future the specific fuel consumption for gas turbines will possibly decrease and they will convert to diesel fuel.

The power of the propulsion plants of existing hydrofoils goes up to 17,000 hp (DENISON), and of military hydrofoils 30,000 hp (PLAINVIEW). These high powers required that the problem of propellers be solved anew. Fixed pitch noncavitating propellers presently are most widespread. As the speeds of hydrofoils increase, ever greater attention is directed to the development of supercavitating propellers. The development of special profiles for the blades and their artificial ventilation is essentially the same as for the foils. Supercavitating propellers have been installed on the hydrofoils BRAS D'OR, PLAINVIEW, and DENISON.

In recent years specialists have devoted much attention to waterjet propellers. They are quite simple, reliable, and inexpensive. Presently in the USSR and abroad efforts are being made to increase their efficiency. Waterjet propellers have been provided on the Soviet CHAYKA, BUREVESTNIK, and in the planned TSIKLON, as well as on the American ships TUCUMCARI, and FLAGSTAFF, and in the planned French passenger ship SA-800 (Fig. 11). The efficiency of waterjet propellers at high speeds approaches that of supercavitating propellers.

It is interesting to note that for convenience of operation seagoing hydrofoils are equipped with auxiliary slow-speed propellers (hullborne). They are either mounted in shrouds on the sides or in auxiliary hinged vertical columns. A variety of different types and arrangements of engine-propeller systems is characteristic of modern hydrofoils. The development of engine-propeller systems and hydrofoil foil systems does not exclude the need to improve hull lines and shape. However investigations in this direction for the purpose of increasing speeds are not major at the present time. Therefore selection of hydrofoil hull elements and shape is made chiefly on the basis of considerations of load-carrying capacity, suitability for industrial production, aesthetics, and weight indices.

For the purpose of reducing ship mass, light aluminum alloys are

Table 2

Main Elements and Characteristics of Some Modern Hydrofoils

Main elements and characteristics	USSR		Switzerland		Italy			France
	TAYFUN	KOMETA-M	PTS150	PT300	RHS140 KONDOR 3	H.57	ALINAVI	SA-800
Displacement, t	65	56.6	165	300	66.5	25	59	56
Load capacity, t	--	24.6	32	--	--	--	--	--
Overall length, m	31.4	35.1	37.5	--	28.7	17.7	22.0	27.7
Waterline length, m	26.5	25.0	36.5	--	--	--	--	--
Overall beam, m	10.0	9.6	7.4	--	10.7	--	7.0	--
Waterline beam, m	5.6	6.0	--	--	6.1	--	--	--
Foilborne draft, m	1.3	1.4	2.7	--	1.5	1.1	--	--
Hullborne draft, m	4.1	3.2	5.5	--	3.5	2.5	--	--
Main engine, hp	GTE 2 x 1700	diesel 2 x 900	diesel 2 x 3000	GTE 2 x 17500	diesel 2 x 1350	diesel 2 x 650	GTE 1 x 4500	GTE 2 x 1300
Speed, knots	44	34-35	35.6	70	32-37	32-38	40-50	56
Passengers	98-105	116	250	550	136	60	--	200
Main propeller	2 props	2 props	2 props	--	2 props	2 props	water-jet	water-jet
Power transmission	angular columns	inclined shafts	inclined shafts	--	inclined shafts	inclined shafts	--	--
Forward foil	deeply submerged	slightly subm.	half-subm.	--	half-subm.	half-subm.	deeply subm.	deeply subm.
After foil	same	same	deeply subm.	--	--	same	same	same

Table 2 (Continued)

Main Elements and Characteristics of Some Modern Hydrofoils

Main elements and characteristics	USSR		Switzerland		Italy			France
	TAYFUN	KOMETA-M	PTS150	PT300	RHS140 KONDOR 3	H.57	ALINAVI	SA-800
Lift control	automatic	--	artificial ventilation	--	--	--	automatic	automatic
Auxiliary engine for hullborne operation, hp	diesel 1 x 165	--	--	--	--	--	--	--
Auxiliary propeller	2 props on retractable columns	--	--	--	--	--	1 prop	--
Sea state operational	5	4	5	--	3-4	--	--	5

Table 2 (Continued)

Main Elements and Characteristics of Some Modern Hydrofoils

Main elements and characteristics	DOLPHIN	TUCUMCARI	PLAINVIEW	Planned	Canada BRAS D'OR	Japan IHF-25
Displacement, t	55-60	60	320	540	212	70
Load capacity, t	11.7	18.7	Above 40	250	47	--
Overall length, m	22.8	21.6	64.6	43.3	46.0	--
Waterline length, m	20.3	20.1	--	41.1	44.8	--
Overall beam, m	5.4	5.9	12.2	21.6	6.6	--
Waterline beam, m	--	--	--	11.9	--	--
Foilborne draft, m	--	--	--	--	2.3	--
Hullborne draft, m	1.3	1.4	1.8	3.7	7.2	--
Main engine, hp	GTE 1 x 3600	GTE 1 x 3500	GTE 2 x 15,600	GTE 2 x 15,600	GTE 1 x 22,000	GTE 2 x 1250
Speed, knots	50	40	40	45	50	45
Passengers	90-120	--	--	--	--	90
Main propeller	1 prop	1 waterjet	2 props	waterjets	2 props	prop
Power transmission	angular column	--	angular columns	--	angular columns	angular column
Forward foil	deeply submerged	deeply submerged	deeply submerged	deeply submerged	semi-submerged	--
After foil	same	same	same	same	same	--

Table 2(Continued)

Main Elements and Characteristics of Some Modern Hydrofoils

Main elements and characteristics	USA				Canada	Japan
	DOLPHIN	TUCUMCARI	PLAINVIEW	Planned	BRAS D'OR	IHF-25
Lift control	automatic	automatic	automatic	automatic	automatic with artificial ventilation	--
Auxiliary engine for hullborne operation, hp	diesel 2 x 216	diesel 1 x 160	diesel 2 x 700	GTE	GTE 1 x 390	--
Auxiliary propeller	2 waterjets	--	2 shrouded props	--	2 props	--
Sea state operational	3	--	To 6	--	5	--

used as the main structural material in modern hydrofoils. Separate sheets of this material may be joined by welding or riveting. Riveted joints are used on Supramar ships, the welding of aluminum alloys has been mastered in the US and the USSR. The foil system is, as a rule, made of stainless steel (Table 3). In the future, the use of carbon fibers is possible in foil construction. For this material an exceptionally high strength to mass ratio is obtained. The carbon thread is obtained through the special processing of artificial polymer. Questions pertaining to the practical use of this material have not yet been resolved /12/.

At the end of the 1960's some specialists began to express doubt in the future prospects of the hydrofoil. Work done in the Soviet Union and abroad, as well as the accumulated experience in hydrofoil operation, proved these doubts to be unfounded /11, 21/. The future development of effective hydrofoils is related to the determination of rational fields of use. At present attempts are being made to define optimal hydrofoil size, power plants, and cargoes that should be carried. There are two points of view on the effectiveness of hydrofoils in the future. European specialists are of the opinion that the operation of commercial hydrofoils on long lines would not be efficient. Therefore the displacement of hydrofoils is not likely to exceed 1000 t in the future. American experience, unlike the European, is based chiefly on the development of military hydrofoils. U.S. specialists believe it is possible to develop larger hydrofoils with automatically controlled foils for ocean travel.

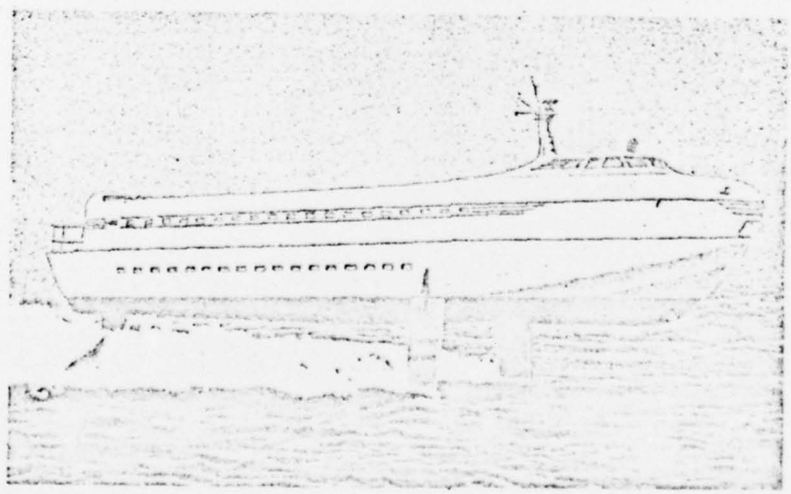

Fig. 11. Sketch of French Seagoing Passenger Ferry for 200 Passengers with Completely Submerged Automatically Controlled Foils.

Table 3

Materials Used for Hydrofoil Hull and Foils

Ship	Al alloy for hull	Material for foils
USSR		
RAKETA, METEOR, CHAYKA	Duralum D16 (riveting) Same	Steel Kh18N9T Forward foil - AMg-61 Al alloy; after - V48-4 alloy
SPUTNIK, VIKHR' KOMETA	AMg-61 (welding) Same	Steel Kh18N9T Steel Kh18N10T
U.S.		
TUCUMCARI, VICTORIA PLAINVIEW, DENISON	--- Alloy 5456 (welding)	Steel Nu-80 ---
Switzerland		
Supramar Company	Al-Mg-Si alloy (riveting)	Steel MSt52-3 (FRG standard) with σ_T = 36kgf/mm^2 and σ_B = 52 kgf/mm^2
Special hydrofoils PTS 150	--- ---	Steel X4CrNiMoNb Low carbon steel with σ_T = 50 kgf/mm^2
Italy		
RHS 110	Peraluman alloy (riveting)	Special steel with σ_B = 52-60 kgf/mm^2
H.57	Al-Mg alloy UNI 3571 brand H10	--- .
Canada		
BRAS D'OR	---	Nickel steel

In their opinion /11/, hydrofoils having a displacement of 4400 t can be planned as early as 1980.

Service on 1000-m sea lines is only a matter of time. On these lines hydrofoils will apparently be able to compete with water-displacing ships. Calculations show that, on the average, the modern hydrofoil will be able to transport three times more passengers and cargo than the conventional ferry of the same displacement.

It must be noted that the speed of hydrofoils in the future is expected to reach 50-60 knots. To a great extent this will depend on successfully overcoming the cavitation barrier. In addition, the hydrofoils of the future will require considerable power (Fig. 12). The theoretical possibility of obtaining such powers has been confirmed by the development of marine gas turbines with power ratings up to 30,000 hp /20/. And the possibility of developing compact nuclear power plants has not been excluded.

Paralleling the development of seagoing hydrofoils, small hydrofoil launches have received widespread acceptance. They are used as excursion, sports, fishing, pleasure, and harbor boats. Many non-Soviet companies in Great Britain, Canada, and Australia produce such ships. This trend has received much impetus. The high-speed British hydrofoil launches, the two-man HI FOIL 2 and the four/five-man K2D CHANNEL SKIPPER, have received considerable acceptance. The U. S. Launch HYDRO MARINE 28 (Fig. 13) is used for excursion and passenger service. The Supramar Company developed the four-man sports launch ST-1 and the patrol boat PT.3. Canada

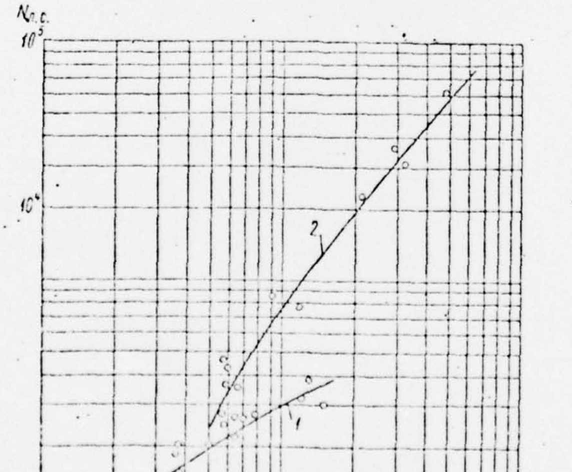

Fig. 12. Growth Trend of Hydrofoil Main Engine Power as Function of Displacement

Fig. 13. American Hydrofoil Passenger Launch HYDRO MARINE 28

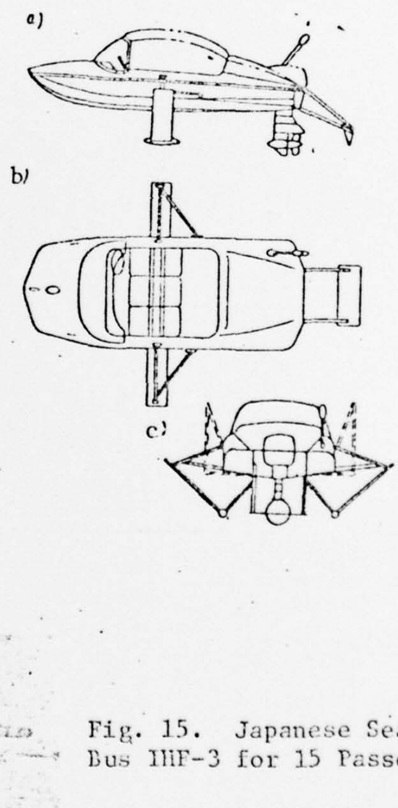

Fig. 14. Canadian 3-Man Sports Launch with Retractable Foils, the 6-A WATER SPIDER. a - sideview; b - topview; c - sternview.

Fig. 15. Japanese Seagoing Bus IHF-3 for 15 Passengers

is producing sports launches with glass-fiber hulls capable of speeds of 35 knots, the one-man 1-A, the two-man 2-A and 2-B /22/, and the three-man 6-A WATER SPIDER (Fig. 14). The seagoing buses IHF-3 (15 passengers) (Fig. 15) and the SF-30 (14 passengers) are used in Japan for inter-island service. The Soviet-built excursion launch VOLGA has won great popularity throughout the world, and the NEVKA hydrofoils will gain wide acceptance in the coming years.

In concluding this survey of the present state of the art and trends in the development of hydrofoils, special note must be made of the role of Soviet shipbuilders in developing this kind of water transport and who have built an entire fleet of hydrofoils of the most diverse kinds. Presently work is underway in the development of considerably more improved hydrofoils. Their seakeeping abilities will be improved by using foil systems with automatically controlled flaps and foil ventilation. Hydrofoil speed should be increased by further improvement of the foils supercavitating profiles. In the future, as the displacement and speed increase, the wide use of gas turbines on hydrofoils must be expected. Diesels will remain only on relatively small and slow hydrofoils. New light structural materials will be developed that will possess improved physical and chemical characteristics, including higher strength stainless steels, reinforced glass fiber, and carbon fiber based materials. Even now the technical and economic prerequisites exist for the development of hydrofoils having a displacement of not less than 1000 t that will operate on 1000-m long lines at speeds of 50-60 knots. In addition to the development of new seagoing hydrofoils, smaller hydrofoils for excursions, sports, harbor work, and other services will be improved.

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